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(54) **COMPOSITE ANTENNA FOR A TIRE**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 11/127,711, filed on May 12, 2005, now abandoned, and a continuation-in-part of application No. 10/902,981, filed on Jul. 30, 2004, now Pat. No. 7,250,914.

(51) **Int. Cl.**
H01Q 1/36 (2006.01)

(52) **U.S. Cl.** **343/897**; 343/711; 152/152.1; 73/146

(58) **Field of Classification Search** 343/897, 343/711; 152/152.1, 539; 73/146, 146.8
See application file for complete search history.

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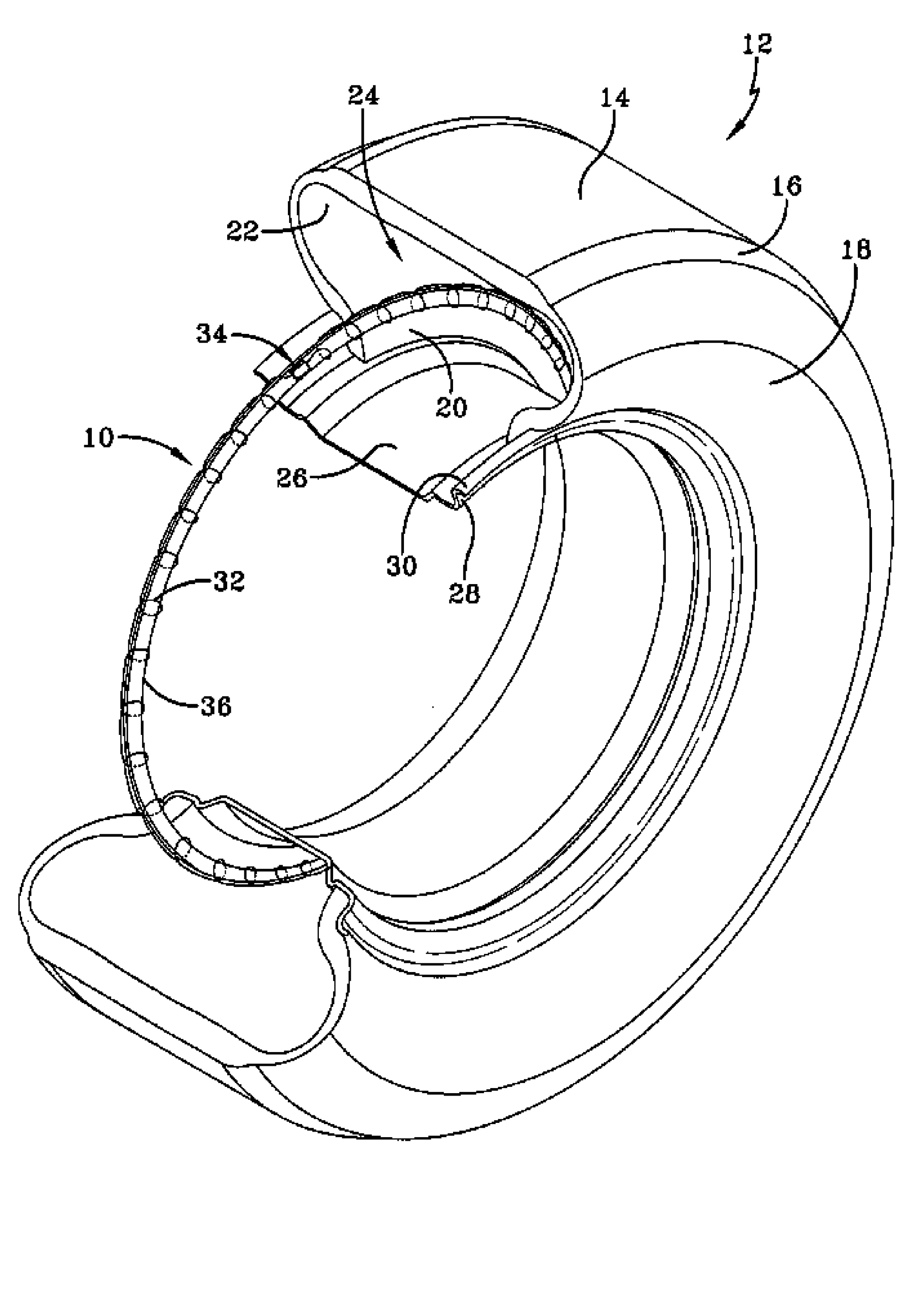
(57) **ABSTRACT**

A composite conductor assembly is configured as a core composed of polymeric elastomeric material and a conductive layer in intimate surrounding contact with the core. The polymeric material provides elasticity to the core to enable the core to elongate when subjected to strain forces within a tire. The conductive layer is fabricated from a low impedance material and may be configured as a composite wherein an inner base metal is selected as a strength member and an outer metallic layer is applied to the base for electrical performance enhancement.

20 Claims, 2 Drawing Sheets



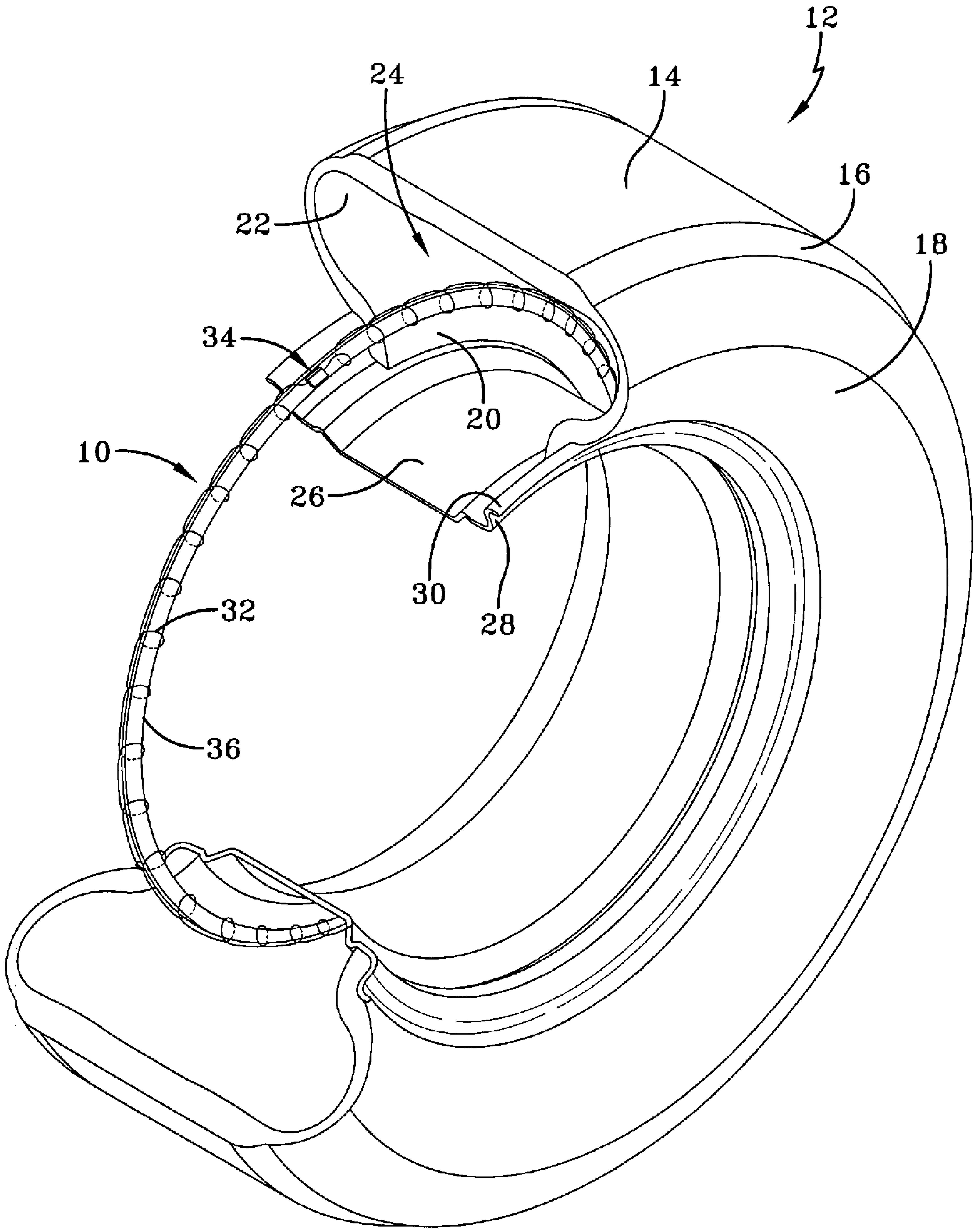


FIG-1

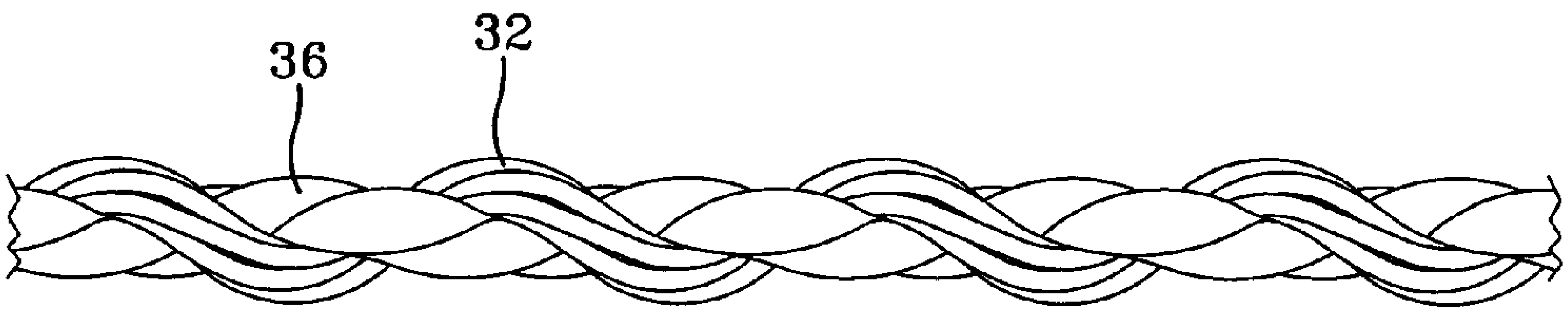


FIG-2

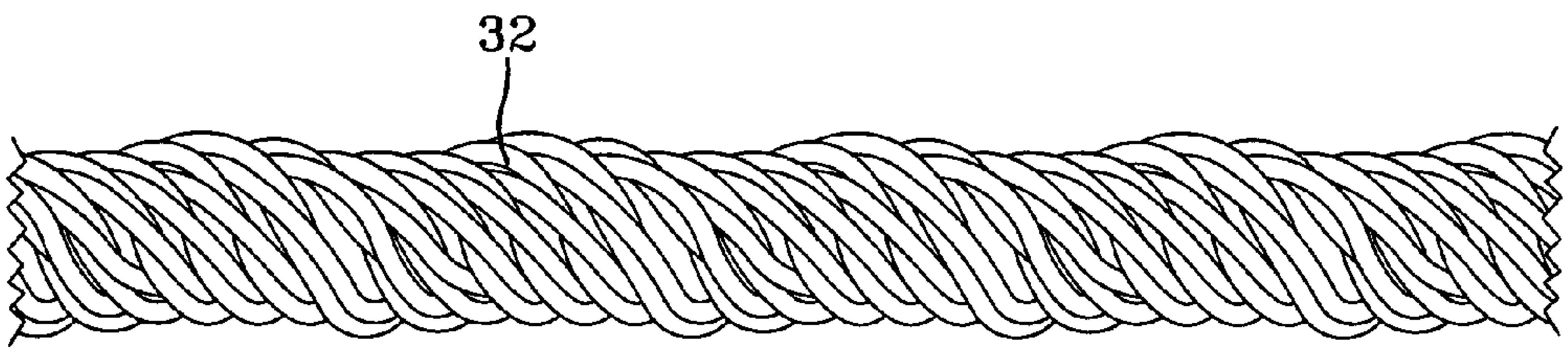


FIG-3

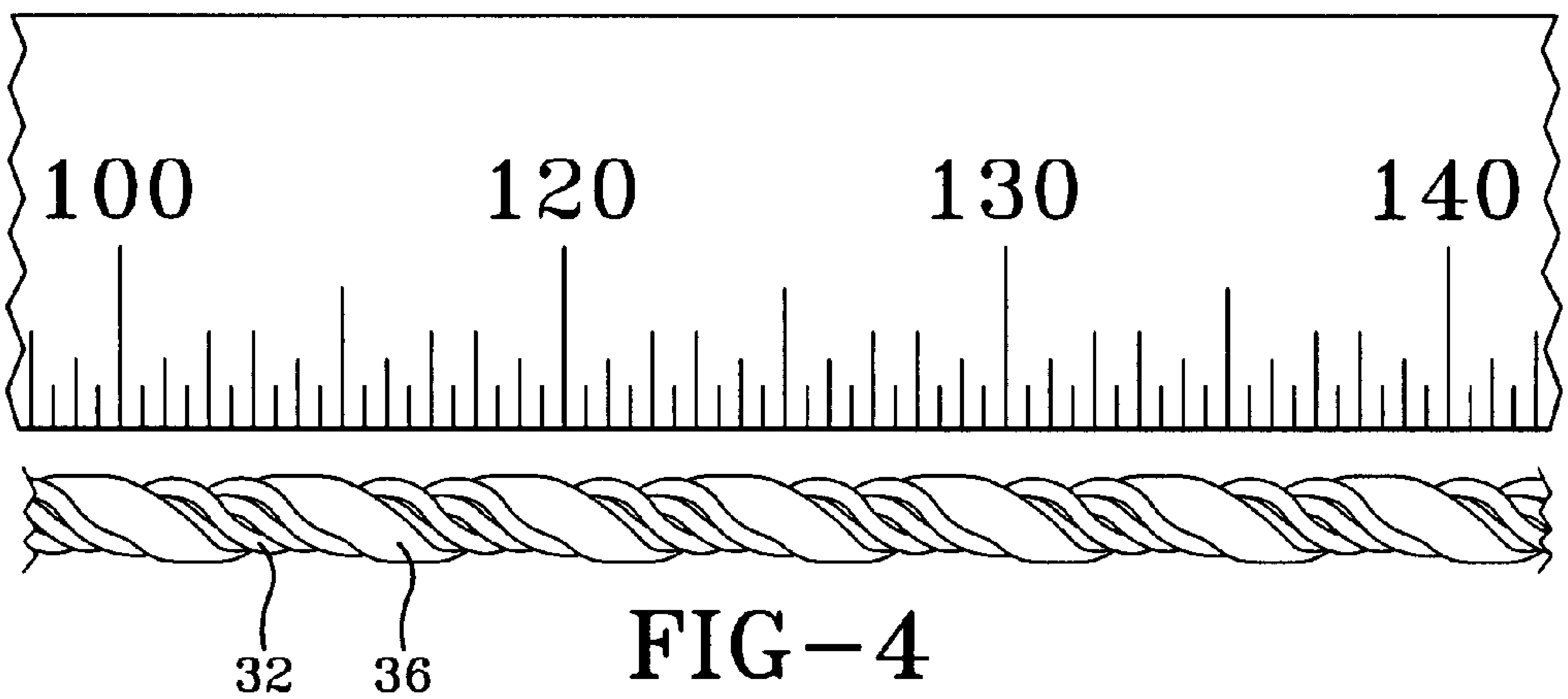


FIG-4

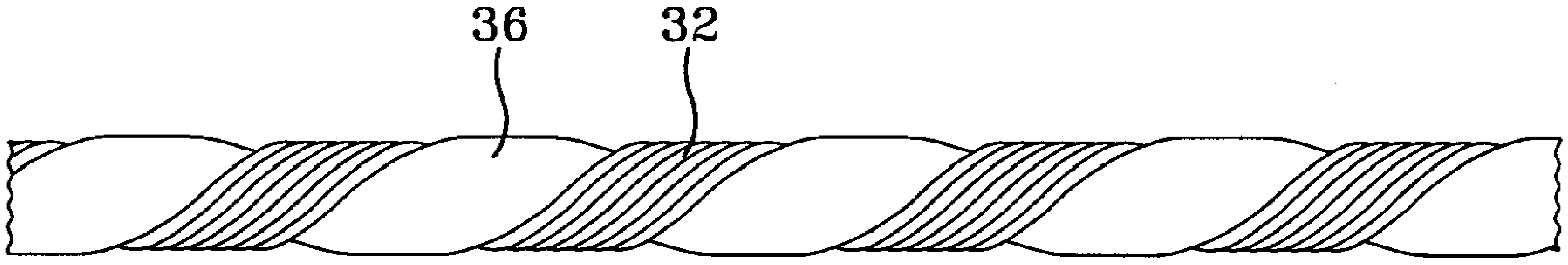


FIG-5

COMPOSITE ANTENNA FOR A TIRE

RELATED APPLICATIONS

This patent application is a continuation-in-part of and claims priority to continuation-in-part application U.S. Ser. No. 11/127,711 filed May 12, 2005 now abandoned, and application U.S. Ser. No. 10/902,981, filed Jul. 30, 2004 now U.S. Pat. No. 7,250,914, entitled "Composite Antenna for a Tire".

FIELD OF THE INVENTION

The invention relates generally to a conductive structure for high strain applications in which a conductor is subjected to repeated flexural strains, such as but not limited to an antenna for incorporation into a tire pressure monitoring system.

BACKGROUND OF THE INVENTION

It is common to employ conductive structure in various high flexural strain applications where the conductor is subjected to repeated flexural strains. Such applications include conductors that extend to moveable apparatus such as doors in the automotive industry. One such application is for apparatus, including an antenna, for electronically transmitting tire or wheel identification or other data at radio frequency. The apparatus includes a radio-frequency transponder comprising an integrated circuit chip having data capacity at least sufficient to retain identification information for the tire or wheel. Other data, such as the inflation pressure of the tire or the temperature of the tire or wheel at the transponder location, can be transmitted by the transponder along with the identification data.

It is known in the art to employ an annular antenna to transmit, at radio frequencies, data from a transponder contained within the structure of a tire or tire and wheel assembly. The antenna comprises a wire or strands of wire formed into a loop that may be sheathed in an extruded covering formed from a suitable material such as plastic. The plastic sheath in combination with the antenna form a unitary body that may be affixed to a green tire in a pre-build assembly process or attached to a finished tire in a post-cure operation. While the antenna and transponder may be incorporated into a tire during "pre-cure" manufacture, in practice it is very difficult to do this. Both radial ply and bias ply tires undergo a substantial diametric enlargement during the course of manufacture. Bias ply tires are expanded diametrically when inserted into a curing press, which typically has a bladder that forces the green tire into the toroidal shape of the mold enclosing it. Radial ply tires undergo diametric expansion during the tire building or shaping process and a further diametric expansion during the course of curing. Any annular antenna and the electronic circuitry associated therewith built into the tire must be able to maintain structural integrity and the mechanical connection between the antenna and transponder package during the diametric enlargement of the tire during its manufacture. Once assembled into the tire, any detected malfunction in the antenna, transponder, or antenna to transponder connection that cannot be repaired destroys the utility of the tire and may necessitate a scrapping of the tire. Hence, placement of an annular antenna-transponder assembly into a tire during its manufacture carries risk that subsequent failure or breakage of assembly components will necessitate the destruction of the otherwise suitable host tire. Regardless of their position within the tire, annular antennas must therefore be able to survive the constant flexing a tire sees in service. This is true for antennas mounted to the inside of a tire's cavity or for antennas cured within the tire's structure.

Not only is the risk of damage to an annular antenna-transponder system present during its incorporation into a tire during manufacture, but damage to such systems are not uncommon from operation of the tire on a vehicle. Loop antennas and the electronics associated therewith are subjected to substantial compressive strain and at the sidewall a high strain amplitude. Such locations represent high load and deformation to regions of the tire. Consequently, antenna, transponders, and the connections therebetween in such locations are prone to breakage and mechanical or electrical failure.

The electrical as well as mechanical characteristics of an antenna are equally important and an antenna that provides satisfactory electrical capability without sacrificing mechanical performance has proven difficult to achieve. Some tire pressure monitoring systems are battery-less and rely on an external power source to power the microprocessor. These systems have complex electrical needs since the antenna must not only transmit a RF signal that reflects the tire's air pressure, but also receive a RF signal that can be turned into power for the microprocessor to operate. There are multiple factors that can negatively affect the antenna's ability to deliver power. Among others, such factors include the distance between the antenna and vehicle mounted transponder; magnetic field distortion caused by the rim; the size of the transformer used near the microprocessor; and the temperature of the tire. Because of these factors and others, it is imperative that the intrinsic electrical impedance of the antenna be kept to a minimum.

There is, accordingly, a continuing need for a conductive structure for high flexural strain applications that maintains structural and conductive integrity throughout repeated flexural strains. In one such application, the conductive structure as an antenna apparatus should be suitable for incorporation into a tire either in a pre-cure or post-cure procedure. The antenna apparatus must provide sufficient structural integrity to withstand the strains attendant tire building processes and post-manufacture use on a vehicle. Moreover, the antenna apparatus ideally will maintain its optimal, intended configuration and shape throughout the tire build operation and subsequent use on a vehicle. Since the performance of the tire pressure monitoring system is dependent upon efficient communication between the tire electronics and a remote reader via the antenna, maintaining the antenna in an optimal configuration is highly desirable. Finally, it is important that any suitable antenna provide low impedance and meet the electrical requirements of the system without sacrificing robust mechanical performance.

SUMMARY OF THE INVENTION

Pursuant to an aspect of the invention, a composite conductor assembly is provided having an elongate core formed at least partially from a flexible, high impedance material; and an elongate conductive layer placed at least partially around the core, the conductor assembly elongating from an initial relaxed state into an extended state in reaction to strain and from the extended state returning to an original, optimal and intended shape when released from the influence of the strain on the conductor assembly.

A metallic material is placed around the core and comprises a conductive layer. The conductive layer transmits the electrical current and may, in one aspect of the invention, take the form of one or more metal filaments wound around the core. The material or materials from which the antenna conductive layer is fabricated provides, pursuant to the invention, low impedance (high conductivity). The conductive layer may be formed from a combination of ferrous and non-ferrous materials in a composite configuration. In one aspect of the invention, a higher strength material may be selected for use as a conductive layer core and a shell of more conductive material formed to surround the core. Other, non-conductive coatings in the conductive layer may be employed to insulate filaments of the conductive layer in order to reduce "skin effect" detrimental to the antenna's electrical performance.

According to another aspect of the invention, the conductive material may be a conductive metal or alloy, drawn through a series of dies to improve fatigue resistance. The conductor may be electroplated with a coating material to provide desired characteristics. The form of the conductor may be round filaments fashioned into an organized helical pattern around the core or multiples of pre-twisted strands of round filaments fashioned into an organized helical pattern around the core. The geometry of the conductor may be defined by the helix angle measured between the respective form of conductive layer and the core layer perpendicular as no less than 15 degrees and no greater than 85 degrees with a preferred angle of between 30 and 50 degrees.

In yet another aspect of the invention, materials forming the conductor assembly are selected wherein at least a portion of the core is formed of at least one material having low loss, high impedance electrical property. For example, material forming the core has a dielectric permittivity less than 0.5 at a frequency of 900 MHz. and a conductivity of less than 0.025 Siemens.

Regarding the core, one aspect of the invention is a core construction composed of a polymeric elastomer or a blend of any other flexible high impedance material that does not degrade the conductive layer and provides high resistance to breakdown from repeated flexural strains and provides a sufficiently high elongation to break characteristic. Another aspect of the invention core is a core formed as a single mono-filament or a multi-filament structure or a braided structure. The core may further be configured having an effective diameter that is at least three times the diameter of the conductive layer.

Pursuant to another aspect of the invention, a tire may be combined with an antenna of the type summarized above. The method for configuring the antenna further comprises yet another aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a tire and the subject annular apparatus with portions of the tire removed for the purpose of illustration.

FIG. **2** is an enlarged schematic view of a portion of a first embodiment antenna apparatus pursuant to the invention.

FIG. **3** is an enlarged schematic view of a portion of a second alternative embodiment of an antenna apparatus pursuant to the invention.

FIG. **4** is a perspective view of the first embodiment of an antenna showing general dimensional scaling.

FIG. **5** is an enlarged schematic view of a portion of a third alternative embodiment of an antenna apparatus pursuant to the invention.

DETAILED DESCRIPTION OF THE INVENTION

A tire pressure monitoring system typically consists of a transponder having one or more sensors. The transponder and associated electronics are housed within a package. In order to send or receive RF signals, a transponder must have an antenna. The antenna is preferably annular in configuration in the subject invention but may have alternative shapes if desired. The antenna may either be incorporated into the tire during manufacture or affixed to the tire by way of a post manufacture procedure. As used herein, an "annular antenna" may be circular, oblong, symmetrical, or asymmetrical without departing from the subject inventive principles. However, the preferred configuration of the antenna is circular and sized to overlap the tire sidewall region to which it attaches. The preferred location is the sidewall, but upper sidewall or crown placement is also possible. Various commercially available transponders, sensors, and other electrical devices may be deployed in combination with an antenna formed pursuant to the principles of the subject invention

Referring initially to FIG. **1**, a preferred embodiment **10** of an annular assembly is shown deployed within a tire **12**. The tire **12** is formed from conventional materials such as rubber or rubber composites by conventional means and may comprise a radial ply or bias ply configuration. A typical tire **12** is configured having a tread **14**, a shoulder **16**, an annular sidewall **18**, and a terminal bead **20**. An inner liner **22** is formed and defines a tire cavity **24**. The tire **12** is intended for mounted location upon an annular rim **26** having a peripheral rim flange **28** and an outer rim flange surface **30**. Rim **26** is conventionally configured and composed of a suitably strong metal such as steel.

With reference to FIGS. **1** and **2**, the assembly **10** comprises an outer conductive antenna layer **32** electrically connected to a transponder **34** and at least partially surrounding and in intimate contact with an antenna inner core **36**. As used herein, the term "composite" refers to the combination of a polymeric core material and a metallic conductive layer material in intimate contact with each other. The core **36** is formed at least partially from a polymeric material and the conductive material forms the conductive layer **32** over the core **36**. The core **36** is herein defined as that material which primarily resides in the center of the antenna and is preferably but not necessarily generally rounded in cross-section. Other forms for the core may be devised within the contemplation of the invention. The core **36** may further consist of one single, noodle-like structure, commonly referred to in the industry as o-ring cord stock. Alternatively, the core **36** may also be comprised of twisted fibers of a polymeric material such as those used to make reinforcing fabrics. By twisting the fibers or yarns, single-ply or more, will increase their elongation properties. Suitable, but not limited to, fibers are polyester, nylon (6 or 6.6), PEN, and others.

Suitable polymers with which to fabricate the core **36** may be either naturally occurring or man-made. One large group of polymers that may be employed are thermoplastics and elastomers; however, the invention contemplates the use of any polymer or combination of polymers that substantially exhibits the properties suitable for the practice of the invention. It is desirable that any suitable material demonstrate a sufficiently large elongation to rupture in tensile test, preferably but not necessarily at least fifteen percent. In addition it is desirable that any suitable material for the core **36** have a sufficiently high breaking load, preferably but not necessarily at least one pound. The material should preferably also demonstrate high fatigue resistance to cyclic mechanical loads; a high material resistance to gaseous degradation; and be chemically inert to the metallic conductive layer that is intimate contact with it. It is further preferable that the antenna core **36** have a diameter of about five times the diameter of the metallic conductive layer surrounding it.

With continued reference to FIG. **1**, a transponder module **34** of the general type described above is provided and may include means for sensing tire parameters such as pressure and temperature. In the post manufacturing state, the apparatus **10** comprising antenna conductive layer **32**, transponder module **34**, and antenna core **36** is a unitary, preferably but not necessarily circular, assembly that is readily transportable and handled for attachment to tire **12**. The diameter of the apparatus assembly **10** is a function of the size of the tire **12** and the preferred tire surface attachment location thereon. The composite antenna maintains the assembly **10** in its intended configuration prior to attachment to the tire inner liner by any suitable means. The apparatus **10** is affixed to liner **22** of the tire **12** either during manufacture of the tire or, as preferable, in a post-manufacture assembly operation. Attachment may be by means of an adhesive or the apparatus may be embedded into the tire itself during manufacture.

When situated in a tire and subjected to strains and heat present within the tire, the antenna will elongate from an initial relaxed state into an extended state. A wavy, sinusoidal, or zigzag shape coupled with the material composition of the antenna conductive layer and core allows the antenna to elongate when subjected to tire strains without breakage. When released from the influence of tire strain, the elastic construction of the antenna core will recover and contract to the original, optimal and intended shape.

The conductive layer **32** functions to transmit electrical current and may take the form of one or more single metal filaments helically wound around the core in a uniform fashion as shown in FIG. **5**. Alternatively, the conductive layer **32** may comprise one or more pre-twisted wire bundles helically wound around the core as shown in FIGS. **2** and **3**.

The conductive layer **32** may be formed from many different types of metallic materials available in the industry such as, but not limited to, copper derived alloys. Acceptable materials for the wire include steel, aluminum, copper, copper alloys or other electrically conducting wire. The diameter of the conductive layer **32** is not generally considered critical for operation as an antenna. A sinusoidal, or zigzag form of the antenna is useful in providing flexibility and minimizes the risk of breakage during manufacture and use. Suitable metallic material with which to form the antenna conductive layer **32** preferably will demonstrate a high ductility after formation over the core **36**. Such material will further demonstrate high fatigue resistance to cyclic mechanical loads of the type and magnitude experienced in a tire environment. Moreover, the material forming the conductive layer **32** will preferably have low electrical impedance at the system's operating radio frequency; low temperature coefficient of resistance; and comprise no environmentally hazardous elements. The core **36** has a longitudinal axis and the conductive layer **32** intersects the core axis at an intersection angle. Such an angle is preferably relatively small so that the conductive layer wraps around the core generally in the same direction as the core axis. The core **36** also may be allowed to wander or deviate from absolute straight. As shown in FIG. **2**, the core **36** undulates under the forces imposed upon it by the conductive layer **32**.

The aforementioned low impedance antenna is of particular utility in an annular configuration to transmit and receive signals from a transceiver. The lower the impedance the antenna has, the further the transponder can be placed from the tire. The subject conductive layer **32** may be formed using non-ferrous elements that provide enhanced conductivity. Alternately, combinations of iron and non-ferrous materials may be employed in a composite structure. Copper or copper based alloys such as Percon 19 may be utilized. Percon 19 is a copper based alloy manufactured and commercially available from Fisk Alloy Conductors, located at Hawthorne, N.J. Copper based alloys offer higher strength than pure copper without sacrificing conductance to an unacceptable degree.

Other materials suitable are those that utilize a higher strength material such as steel for the conductive layer base material and a more conductive material such as copper or a copper alloy around the base material. The antenna conductive layer may further be used with a thin conductive electroplated coating such as but not limited to tin, gold, or silver. The coating can aid in soldering the conductive layer to the transponder terminals and also prevent the base material from corroding.

In addition to the use of conductive coatings, non-conductive coatings may be employed for coating the conductive layer **32**. One such coating is polyurethane. Such a coating can be applied to a conductive base material. For a conductive layer that is made up of many fine filaments rather than a solid conductor, insulating each filament reduces what is commonly called the "skin effect". The skin effect is detrimental to an antenna's performance and occurs when all of the conductors in the antenna conductive layer are not utilized equally; i.e. the inner areas of the antenna conductive layer are not contributing as effectively as the outer.

The combination of a low impedance outer conductive layer with a flexible polymeric inner core provides significant advantageous mechanical and electrical properties. The antenna is flexible and yet provides good conductivity. By way of example, without limiting the use of substitute materials, an antenna may be configured having a core **36** formed at least partially from Nylon 6.6, two ply yarn (thermoplastic) and a conductive layer **32** of 1+6×0.175 mm, Percon 19 (pretwisted as in FIG. **2**). Another composite may be formed using a core **36** formed at least partially from Polyester, two ply yarn (thermoplastic) and a conductive layer of 6 pretwisted bundles of 3×0.175 mm, Percon 19 as shown in FIG. **3**. An alternative composite antenna may be formed using a core **36** formed of SBR, carbon black filled (elastomer) and a conductive layer **32** of (7) 0.175 mm, Percon 19 (single layer as shown in FIG. **5**).

In general, therefore, the conductive material may be a conductive metal or alloy (such as but not limited to copper, aluminum, and iron), drawn through a series of dies to improve fatigue resistance. The conductor may be electroplated with a coating material (such as but not limited to material providing corrosion protection, enhanced solderability and/or conductivity) to provide desired characteristics. The form of the conductor may be round filaments fashioned into a n organized helical pattern around the core (such as but not limited to single layer of side-by-side filaments) or multiples of pretwisted strands of round filaments fashioned into an organized helical pattern around the core. By way of example without intent to limit the invention, y strands of nxm structures or y strands of n+m+k structures may be employed where y=1 to 50; n=1 to 7; m=1 to 27; and k=0 to 27. The geometry of the conductor may be defined by the helix angle measured between the respective form of conductive layer and the core layer perpendicular as no less than 15 degrees and no greater than 85 degrees with a preferred angle of between 30 and 50 degrees.

Regarding the core, the invention employs a core construction composed of a polymeric elastomer (such as but not limited to nylon, polyester, aramid, and/or rubber)or a blend (such as but not limited to merged cords like Aramid-Nylon, Nylon-Polyester) of any other flexible high impedance material that does not degrade the conductive layer and provide high resistance to breakdown from repeated flexural strains and provides a sufficiently high elongation to break characteristic. Another aspect of the invention core is a core formed as a single mono-filament (such as but not limited to fishing line or rubber o-ring stock); or a multi-filament structure, twisted or non-twisted bundles (such as but not limited to yarns, multi-ply cords with directional twists); or a braided structure, flat or round (such as but not limited to anchor lines, towing ropes or safety ropes. The core may further be configured having an effective diameter that is at least three times the diameter of the conductive layer.

While the subject invention has particular utility fur use as a conductor in a high flexural strain application such as an antenna affixed to a tire, the invention is not intended to be so limited. The invention can also be applied to other high flexural strain applications that require that a deployed conductor maintain structural and conductive integrity throughout repeated flexural strains.

In certain electrical applications, materials may be selected for the core and conductor to exhibit desired electrical characteristics. Some basic material RF properties are the magnetic permeability μ and the dielectric permittivity ∈. These are defined by the relations between electric flux density D and the magnetic flux density B and the electric field E and magnetic field H.

$$D=\epsilon E$$

$$B=\mu H$$

Their values are denoted with a subscript $_0$ to mean the values for vacuum

$$\epsilon_0=8.854\times10^{-12}\text{ farad/m}$$

$$\mu_0=4\pi\times10^{-7}\text{ henry/m}$$

and the relationship of materials in relation to vacuum may be evaluated.

$$\epsilon_r=\epsilon/\epsilon_0$$

$$\mu_r=\mu/\mu_0$$

The permittivity values reported (range 5-50) are the relative values. Rubber is nonmagnetic ($\mu=\mu_0$).

The speed of propagation of an electromagnetic signal in a medium is

$$c=\frac{1}{\sqrt{\mu\varepsilon}}$$

and the wavelength for a frequency f is

$$\lambda=\frac{c}{f}.$$

For a given frequency the wavelength depends on c which depends on the medium. Antennas are sized in relation to the wavelength that they are designed for. An antenna that is embedded in a material with $\epsilon_r=4$ is ½ as large as one in free air. The permittivity of the rubber effects the antenna tuning.

Like mechanical energy which may have loss in viscoelastic materials, electrical energy can be lost in propagation of a signal through a material. Storage and loss relative permittivities ∈' and ∈" are defined. Then

$$\epsilon^*=\epsilon_0(\epsilon'-j\epsilon'').$$

$$\tan\delta=\epsilon''/\epsilon'$$

is a measure of how lossy the material is.

The effective conductivity for alternating currents at radial frequency ω is

$$\sigma=\epsilon''\epsilon_0\omega.$$

The loss of energy in a material is related to its effective conductivity that at a given frequency depends on the complex part of the permittivity. It is desirable to use low loss (high impedance) materials for the core, at least that portion of the core particularly in contact with the antenna. Materials with $\epsilon''<0.5$ are useful at typical UHF RFID frequencies of around 900 MHz. This translates to an effective conductivity target of <0.025 Siemens.

Therefore, while the above sets forth a preferred embodiment and alternative embodiments of the subject invention, the invention is not intended to be so limited. Other embodiments that will be apparent to those skilled in the art and which utilize the teachings herein set forth are intended to be within the scope and spirit of the present invention.

What is claimed is:

1. A composite conductor assembly comprising:

an elongate core formed at least partially from a flexible, high impedance material;

an elongate antenna conductive layer placed at least partially around the core, the antenna operably flexibly deforming through reciprocal elongation and contraction in reaction to externally originating stresses, wherein the core is comprises a plurality of side-by side disposed bodies composed at least partially of the flexible, high impedance material and forming a bundle, the core bodies flexibly reciprocally elongating from an initial relaxed state into an extended state in reaction to externally originating stresses imposed on the antenna, and contracting from the extended state returning to an original, optimal and intended shape when released from the influence of the externally originating stress, and flexibly radially deforming into an undulating configuration under forces imposed by the conductive layer.

2. A conductor assembly according to claim **1**, wherein the core comprises a unitary elongate body composed from at least one polymeric elastomer.

3. A conductor assembly according to claim **2**, wherein the core is composed from at least one material taken from the group (nylon, polyester, aramid, rubber).

4. A conductor assembly according to claim **1**, wherein the core is a single mono-filament structure.

5. A conductor assembly according to claim **1**, wherein the core is a multi-filament structure.

6. A conductor assembly according to claim **1**, wherein the core is a braided structure.

7. A conductor assembly according to claim **1**, wherein the core has a diameter that is at least three times the diameter of the conductor layer.

8. A conductor assembly according to claim **1**, wherein the core is composed from at least one material having an elongation to break characteristic greater than about 5%.

9. A conductor assembly according to claim **1**, wherein the core is composed from a material that causes no substantial degradation in the conductive layer.

10. A conductor assembly according to claim **1**, wherein the conductive layer comprises at least one filament in a helical pattern around the core.

11. A conductor assembly according to claim **1**, wherein the conductive layer comprises a plurality of pretwisted strands in a helical pattern around the core.

12. A conductor assembly according to claim **11**, wherein the helical pattern is alternatively at the election of a user y strands of nxm structure or y strands of n+m+k structure wherein y=1 to 50; n=1 to 7; m=1 to 27; and k=0 to 27.

13. A conductor assembly according to claim **1**, wherein the conductive layer comprises at least one filament in a helical pattern around the core, the helix angle measured between a respective form of conductive layer and the core perpendicularly is substantially between 15 and 55 degrees.

14. A conductor according to claim **1**, wherein the conductive layer comprises at least one filament in a helical pattern around the core, the helix angle measured between a respective form of conductive layer and the core perpendicularly is substantially between 30 and 55 degrees.

15. A conductor assembly according to claim **1**, wherein the conductor layer is composed of at least one conductive metal and the at least one conductive metal of the conductor layer is coated with a secondary material.

16. A conductor assembly according to claim **1**, wherein the conductor assembly deforms into an undulating configuration in the extended state.

17. A conductor assembly according to claim **1**, wherein at least a portion of the core is formed of at least one material having low loss, high impedance electrical property.

18. A conductor assembly according to claim **17**, wherein the at least one material has a dielectric permittivity less than 0.5 at a frequency of 900 MHz.

19. A conductor assembly according to claim **18**, wherein the at least one material has a conductivity of less than 0.025 Siemens.

20. A conductor assembly according to claim **17**, wherein the at least a portion of the core contacts the conductive layer.

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